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GEOLOGIC SITE CHARACTERIZATION REQUIREMENTS FOR STORAGE AND MINING IN SALT

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ABSTRACT

Geologic Site Characterization should be a dynamic, continuing ***process***, not an event. Its successes and failures are legion and can make or break an operator. A ***balanced*** approach must be sought to provide adequate information for safety of operations, neither slighting nor overdoing the effort.

The evolving nature of study methods and geologic knowledge essentially mandates that characterization efforts be reviewed periodically. However, indifference, nonchallance, and even outright disdain describe attitudes witnessed in some circles regarding this subject. Unawareness may also be a factor. Unfortunately, several unanticipated events have led to severe economic consequences for the operators. The hard-learned lessons involving several unanticipated geotechnical occurrences at several Gulf Coast salt domes are discussed.

The ultimate benefit of valuing site characterization efforts may be more than just enhanced safety and health—costs not expended in lost facilities and litigation can become profit.

DISCLAIMER

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INTRODUCTION

Geologic Site Characterization (GSC) is a necessary prerequisite for the emplacement of storage and mining facilities in salt, but is given unequal attention by different operators. This results from a combination of differences in regulatory requirements, salt environments, and perceptions of what is necessary. The geologic storage of nuclear and toxic waste has distinctive regulatory requirements and is not specifically discussed here, but many of the same principles apply.

Several principles of GSC are reviewed, and some practical suggestions made for implementing them, including periodic updating to ensure currency. While geologic conditions are usually slow to change, man's understanding of them is continually evolving and this requires re-evaluation of previous assessments.

WHITHER GSC?

The requirement for GSC has its roots in *personal and environmental safety*, but the principal benefit to the operator ultimately may be *cost savings*. GSC for engineered works must at least consider the complete range of topics relating to the natural environment, even when thought to be of little concern at specific sites. For most salt storage and mining projects a reasonable *balance* must be sought, and GSC activity must proceed in parallel with regulatory and engineering criteria to achieve this.

Premature judgment regarding site suitability has arisen sometimes when promoters of projects have sought to bring facilities on line as quickly as possible, or when marginal or even defective conditions have existed. While such behavior may be expedient and understandable, it also must be challenged, especially involving uncertain conditions having adverse safety or environmental consequences. Hindsight shows that many incidents resulting from incomplete site characterization could have been avoided, had more attention been given to specific topics at the outset.

SALT ENVIRONMENTS

Generalizations about the siting of caverns and mines are difficult, owing to the rich variety of salt depositional environments and structures that exist, even in the United States alone. The following examples show major distinctions, and some types of problems that exist in each. Such becomes the grist for GSC.

Domal salt is perhaps best known because of its association with oil production and extraction of salt and sulphur minerals for more than 100 years. From studies of the more than 250 onshore salt structures in the five subbasins of the Gulf of Mexico Basin, it is clear that none are alike. Most show significant differences in origin, size, shape, and features. Yet because of the common derivation from the Louann "mother" salt and analogous diapiric processes, there are also many similarities, at least on a regional scale. In the past 20 years, revolutionary concepts have changed the way geologists regard salt dome processes and structures. For these reasons, the task of GSC must be to identify the distinctions and evaluate them individually within the context of the specific storage or mining project. The very nature of salt diapirism (vertical structures) makes domal salt inherently more difficult to characterize as compared with bedded salt, but caverns are substantially easier to solution mine. Conventional mining may have fewer differences.

The boundaries between spines or lobes in salt domes imply differential motion between separate units, forming shear or anomalous zones (AZs). These zones have been conceptualized primarily as a result of geologic mapping in underground mines (Kupfer, 1976, 1990, 1995a), but have been difficult to identify in most storage projects where subsurface mapping is derived from geophysics. However, because of difficulty encountered in several projects, concerted characterization efforts to map them may be warranted. More than 1000 caverns have been created for brining and storage in the United States and only a few have shown evidence of having encountered AZs.

The central graben mapped in the caprock at Big Hill, Texas, was identified *after* 14 caverns had been constructed for the Strategic Petroleum Reserve **(Figure 1).** After the fact it seemed easy to say this marked an anomalous zone, but the experience gained earlier during cavern leaching showed that anomalous features could be correlated (Neal, et al., 1993). Such central grabens between AZs may be commonplace but are difficult to recognize as noted above. Kupfer (1995b) has noted the uncertainty with the association of grabens and AZs.

Bedded salt is more prevalent in area than domal salt **(Figure 2),** but frequently less usable because the shallow deposits have undergone extensive dissolution, and deeper deposits have been deformed or are impractically deep. Market locations and/or transportation access are common logistical constraints for storage and mining. Physical constraints that inhibit development include bed thickness and interbedding of clastic units, frequently contributing 25% and more of insolubles.

The Upper Silurian Salina group, for example, contains up to 17 individual salt beds, a few of which extend from Michigan to West Virginia. Along the thin western edge of this evaporite basin, salt thickness is primarily determined by filled-in sinkholes or paleokarst topography. Low-angle, gravity-thrust faults (fluid-thrusts: Kupfer, 1995c) are observed in deeper salt sections, and true reverse thrusts are found in and best documented in salt mines.

Only the thinner beds still have their original thickness intact over an entire storage or brine field, because salt is always creeping and the rate is proportional to the square of the bed thickness (or diameter).

Dissolution of the salt mass usually begins very early in the history of the salt deposit. The salt is often dissolved around the margins of enclosing reef structures, such as the Niagaran in the Michigan Basin, and the Capitan in the Delaware Basin of New Mexico and West Texas. The salt is sometimes dissolved by seawater soon after deposition and subsequently by groundwater. The fractured reef rocks are more transmissive to groundwater incursion and provide conduits for dissolution.

Cavern storage projects have been proposed with as little as 90 feet of bedded salt in New York State near an LPG storage facility that thickens in a salt ridge with 200 feet of continuous salt. Such thickening of salt in otherwise uniform, thin beds provides hope for storage in otherwise negative environments and is discussed later. At Holbrook, AZ, short and flat LPG caverns were constructed in just 225 ft of bedded Supai salt at depths of 1000 ft below the surface **(Figure 3)**. At Glendale, AZ, much larger, taller and more slender LPG caverns were emplaced at depths of 1500-3000 ft because diapiric rise had thickened the deposit.

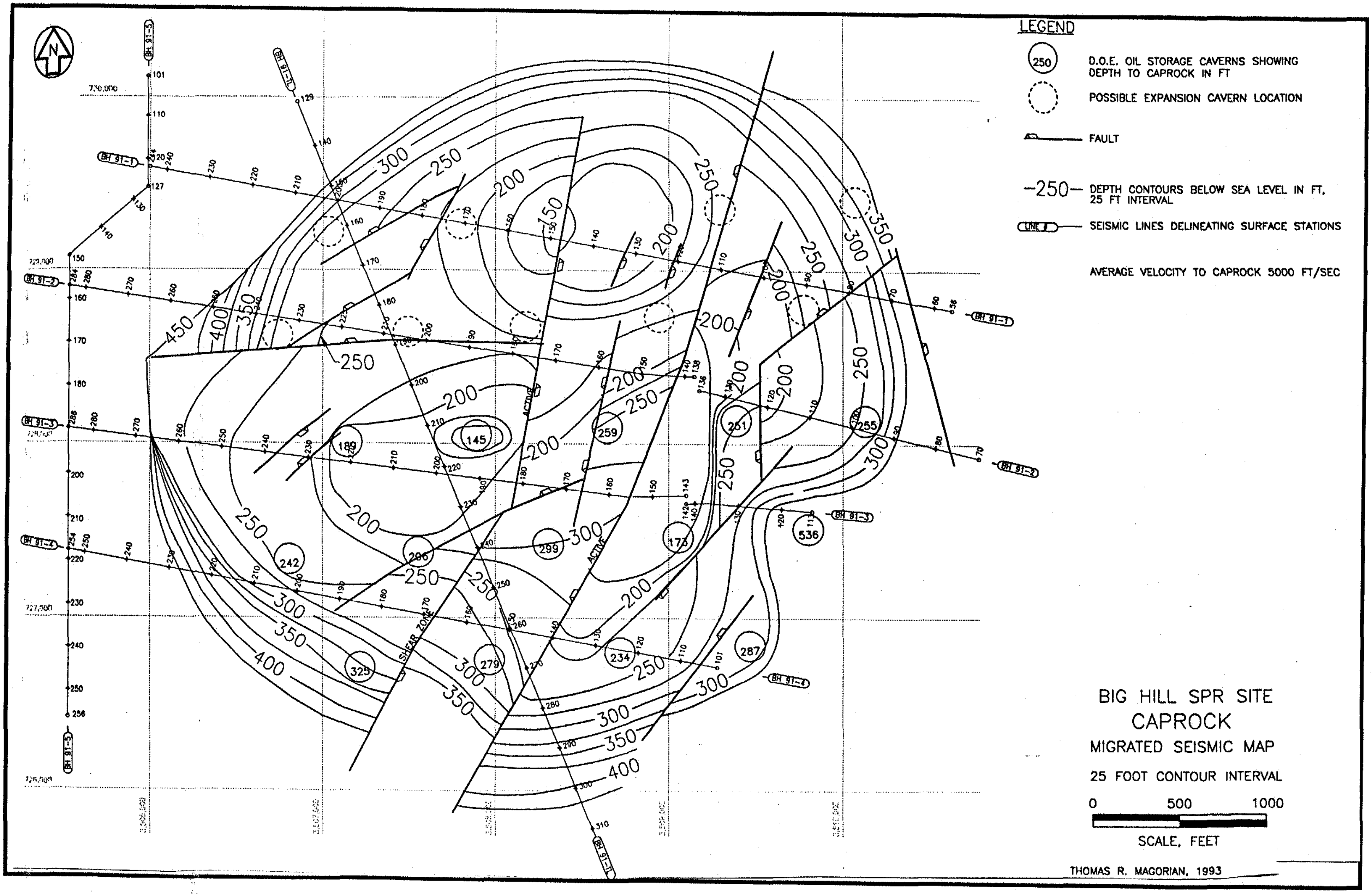


Figure 1 Map of caprock at Big Hill salt dome, TX. Contours obtined fron reflection seismic profiling and numeous wells. The central graben manifested in the caprock may be substantially wider than the AZ in the underlying salt.

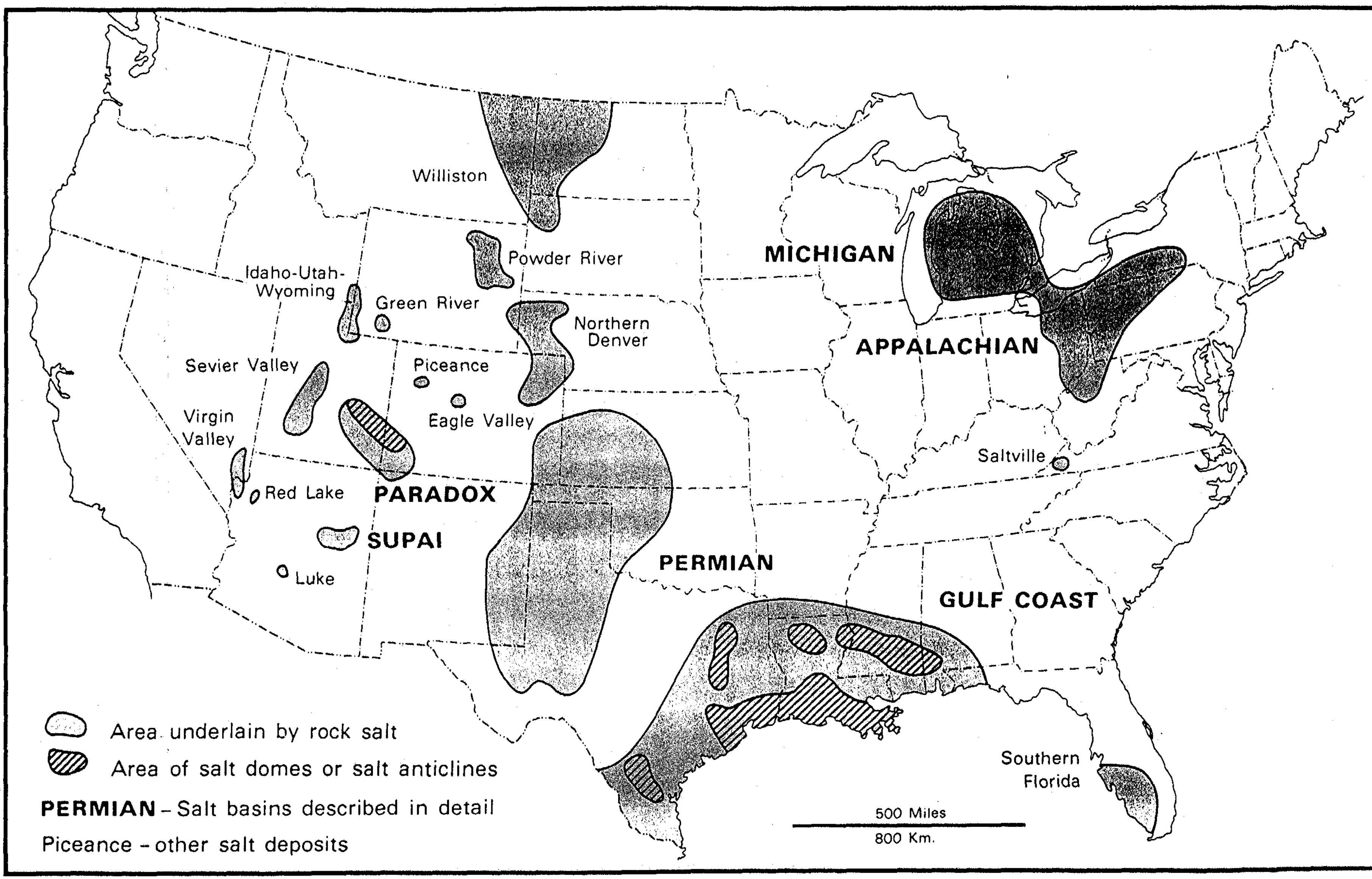


Figure 2. Map showing rock-salt deposits in United States.

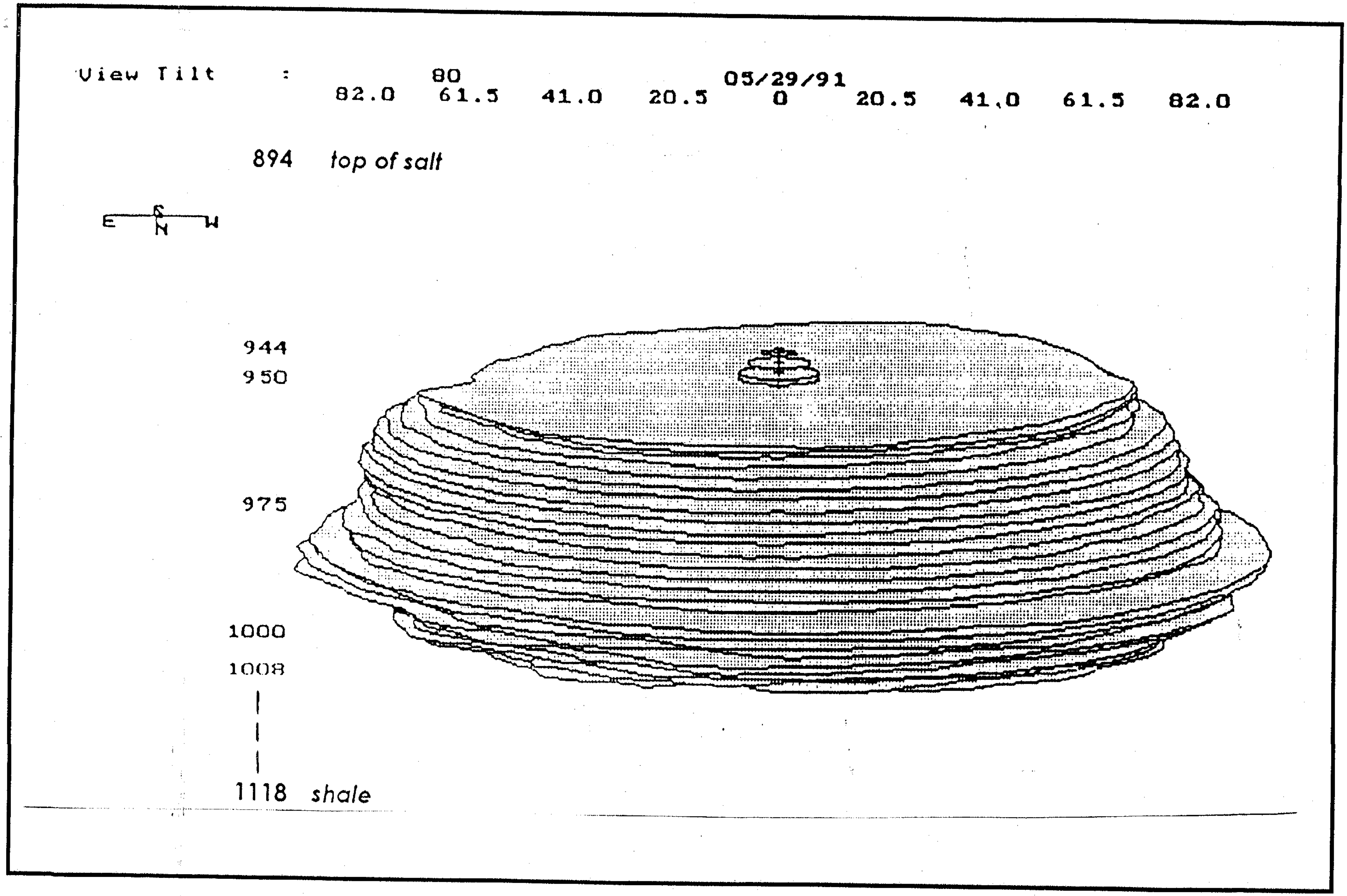


Figure 3 Caverns in Arizona's Supai Salt Basin require short, squat configurations for LPG caverns at Adamana, AZ. Sonar survey of Ferrelgas Cavern 3 reveals cavern height of 164 ft in salt section of 224 ft.

These conditions would also be suitable for natural gas storage.

The technology for developing storage in thinly bedded salts is immature in comparison with thicker beds and domes, but many concepts are being considered, including multiple well galleries and horizontal drilling. Cavern development technology in thin beds may be further along than the ability to map the caverns with existing sonar methods.

Salt Anticlines and ridges occur in many bedded salt deposits as a result of arching and/or faulting upward along regional structural trends, often in conjunction with holokinesis. These features are well known in the Paradox Basin of Utah and Colorado and in the Salina Salt in the Michigan and Appalachian Basins of the Northeast. Younger sediments are draped over these structures, commonly forming "piercement" anticlines in the Paradox Basin **(Figure 4)**, and many non-piercement structures in the Michigan and Appalachian Basins. These structures have been perennial targets for oil and gas exploration.

The Tioga Anticline along the New York-Pennsylvania state line is an example of a piercement anticline **(Figure 5).** Developed originally as a Devonian Oriskany gas field, it was converted to seasonal depleted-reservoir storage following 15 years of primary production. The Oriskany sandstone is naturally fractured on the crest of the anticline, next to the central graben, and delivers up to 60 MMCF per day per well. Many if not all piercement salt-cored anticlines have a central graben or down-faulted block along the crest. Between the Oriskany and the Salina is 500 ft of lower Devonian limestone overlying a massive anhydrite "caprock." Similar residual caprocks are noted on other salt anticlines, often consisting of gypsiferous material, or concentrated clastic residuum.

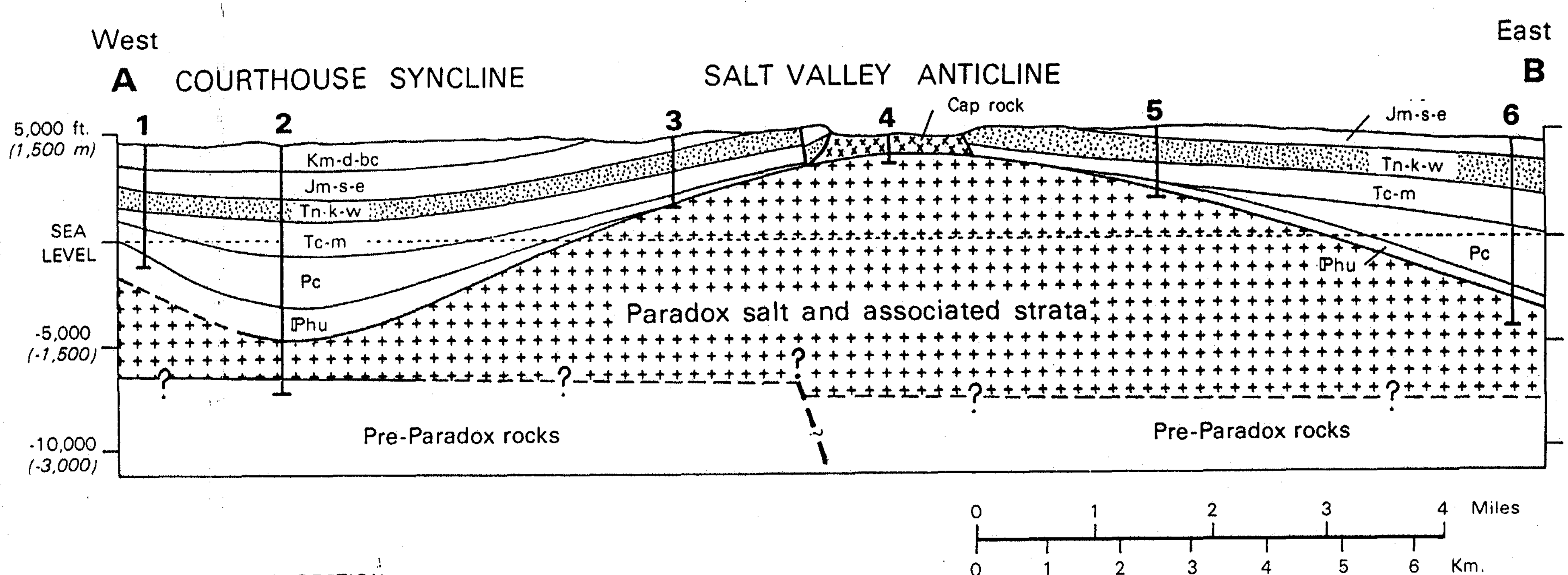
At Tioga, the underlying salt anticline was penetrated by only one dry hole, 500 ft low down the plunge of the crest. It was so far from the producing wells that its records had been lost by the storage operator. After a gravity survey established that the ridge was mostly salt, a storage well was deepened to the underlying Niagaran reef, penetrating 2210 ft of salt with 25% insolubles **(Figure 5).** The insolubles consisted of small broken fragmenrts of black shale and gray dolomite, allowing development of similar size caverns as are standard in Gulf Coast domes. However, the underlying Niagara is an off-reef facies of tight green marble; low permeabilities constrain brine disposal, thus project development.

Along the thick eastern edge of the Appalachian Basin, thicker ridges include increasing amounts of shale, similar to the shale sheath found around deep salt domes in the the Paradox Basin and Gulf Coast, around salt ridges and sills. The same operator at Tioga previously drilled through the salt section on the next, even higher, ridge into the basin, the Leidy structure which is the largest gas storage field in the east, finding mostly diapiric shale with no single salt body more than 200 ft thick. As with most salt structures, extrapolations are risky.

REGULATORY REQUIREMENTS

The motivation for conducting GSC is obvious for industrial facilities in active seismic areas such as California or Japan, especially for high risk activities such as nuclear power plants where regulatory proscriptions are formidable. For Gulf Coast storage and mining there are entirely different natural threats and the approach is generally much less rigorous, at least regarding seismicity. Thus, engineering judgment and common sense must dictate what level of GSC is needed for sprcific applications, and *history* is our guide. However, we suspect that history is often soon forgotten and its lessons must be relearned.

Engineers prefer not to overdesign for reasons of cost, but neither is it desirable to *un-*



WELLS USED IN SECTION

1. Equity, Donahue No. 1
2. Texaco, McKinnon No. 1
3. Continental, Gov't.—Hall No. 1
4. Western Allies
5. Pure, Salt Valley No. 1
6. Union, Devils Garden—USA No. 1

Km-d-bc	Mancos-Dakota-Buro Canyon
Jm-s-e	Morrison-Summerville-Entrada
Tn-k-w	Navajo-Kayenta-Wingate
Tc-m	Chinle-Moenkopi
Pc	Cutler
IPhu	Hermosa (Upper Member)

Figure 4 Cross section through Salt Valley piercement anticline in Grand County, Utah (modified from Hite and Lohman, 1973). Excess salt beneath anticline is problematic and should be regarded as diagrammatic rather than actual. From Johnson and Gonzales, 1978.

Figure 5
Tioga piercement anticline, showing local thickening adjacent to fault structures

Need — location / scale
North
source / reference
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location of well?

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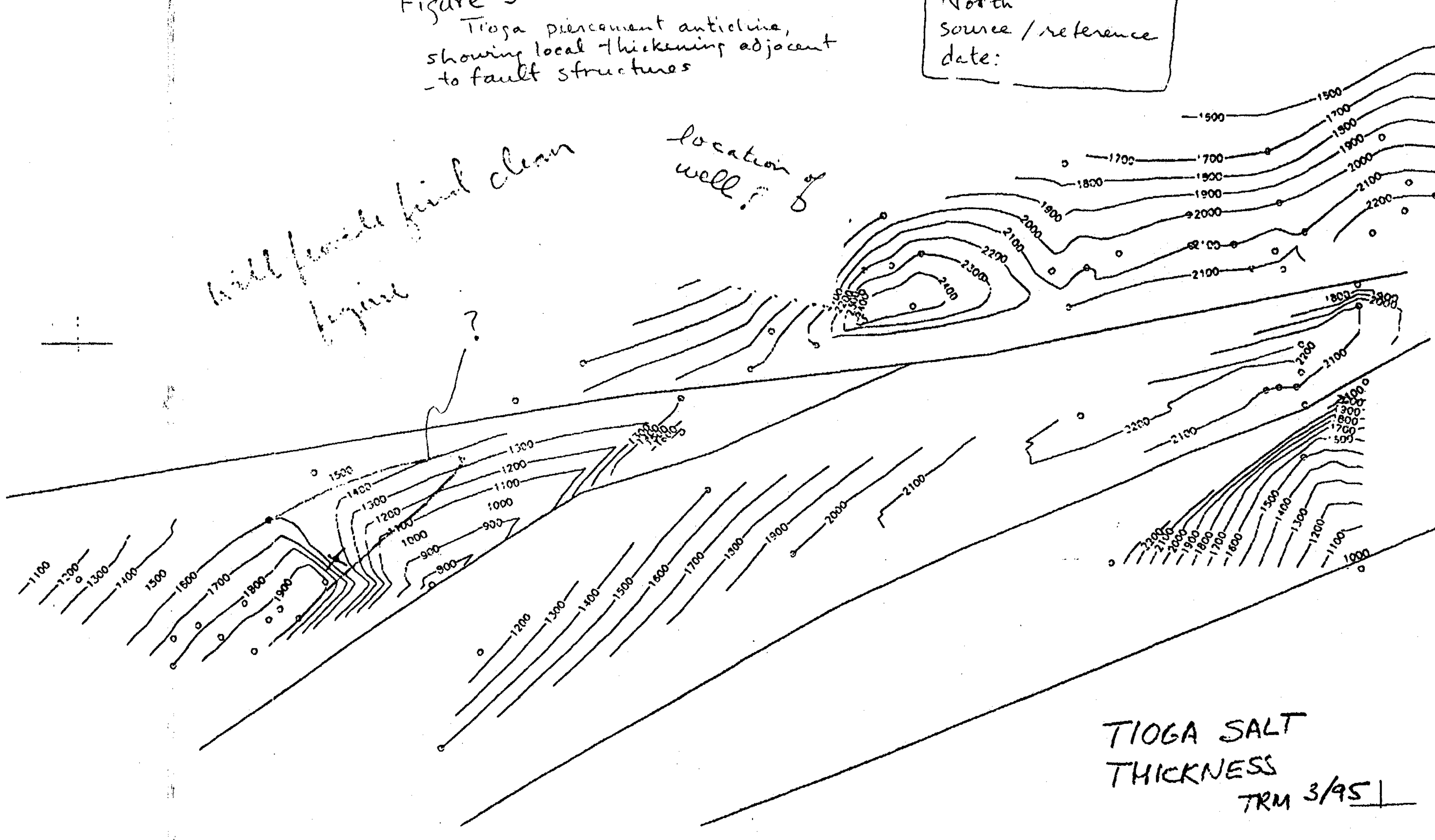


derestimate requirements, as costly retrofits (even if possible) may become necessary. Seismic hardening in earthquake zones is a case in point, which, after the fact, can be a difficult engineering challenge. Unfortunately, with storage caverns in salt, there are practical limits to what can be done to alter mistakes made during the initial emplacement.

Salt storage projects in Arizona, Louisiana, Mississippi, and Texas are regulated by similar and yet distinctive rules within each State. They differ for a variety of reasons. A characteristic of all is that they abhor specificity, and rely on *demonstrating* essential safety of proposed projects through the mechanism of hearings that are backed up by voluminous study documents produced by consultants. There is generally little proscription that limits specific conditions, and exceptions are allowed, again based on reasonable demonstration. The broad nature of salt environments discussed earlier is perhaps the principal reason for limiting specificity. The system has generally worked well, and a few leading firms in the industry have enjoyed preeminence over the years. However, some rethinking on regulatory definition may be in order.

The range of geotechnical topics requiring consideration is outlined in **Table 1**. The emphasis to be placed on specific subject matter must be gained from experience and engineering judgment. There have been few attempts to control the range of geologic topics required in permitting other than the Canadian standard for underground storage of hydrocarbons (Canadian Standards Associsation, 1993).

Within some states, e.g., Texas, sufficient variability exists from east to west that geologic processes and events may be quite different. Groundwater may be at the surface near the Louisiana border but much deeper in the High Plains on the New Mexico side, making requirements for deterring hydrocarbon leakage different in each environment. Such variability makes the task difficult for the regulator, but supports the concept of site-specific permitting. In the arid west, with vastly different hydrology, both raw water and brine disposal may be critical.

And even though Federal, state, and local regulations dictate what types of studies must be accomplished for various types of projects, ***usually there is no requirement to reevaluate the initial conclusions.*** Too often that happens only after trouble is experienced, and sometimes only in accident investigation reports. The U. S. Department of Energy (DOE) now requires natural phenomena hazard assessments as a matter of course, *and* requires updates at 10 yr intervals, or as otherwise indicated (DOE, 1993, 5480.28). GSC updating was planned for in the early days of the SPR program, even before the subsequent DOE requirement. The remaining discussion makes a case for continuing, periodic updates to GSC.

EVOLVING CHARACTERIZATION TECHNOLOGY

In addition to the evolving conceptual understanding of salt deposits and processes, means of study have changed, in turn contributing to conceptual advancement. The ability to obtain quality geological data, especially from geophysical exploration, has improved markedly in the past 20 years and this has significantly aided more accurate GSC for cavern storage, but at increased cost. For example, 3-D reflection seismic methods have revolutionized the geologic picture offshore. Onshore, vertical seismic profiling (VSP) and salt proximity surveying, combined with precision directional drilling, have provided a more detailed view of many dome edges. High resolution profiling over the tops of domes has shown detailed structure previously unknown (Figure - Stratton). The map of Big Hill (Figure 1) was produced by modern seismic reflection profiling. It differs significantly from the earlier interpretation, and is causing rethinking about anomalous zones in salt (Magorian et al., 1993). This in turn may affect our decisions about how

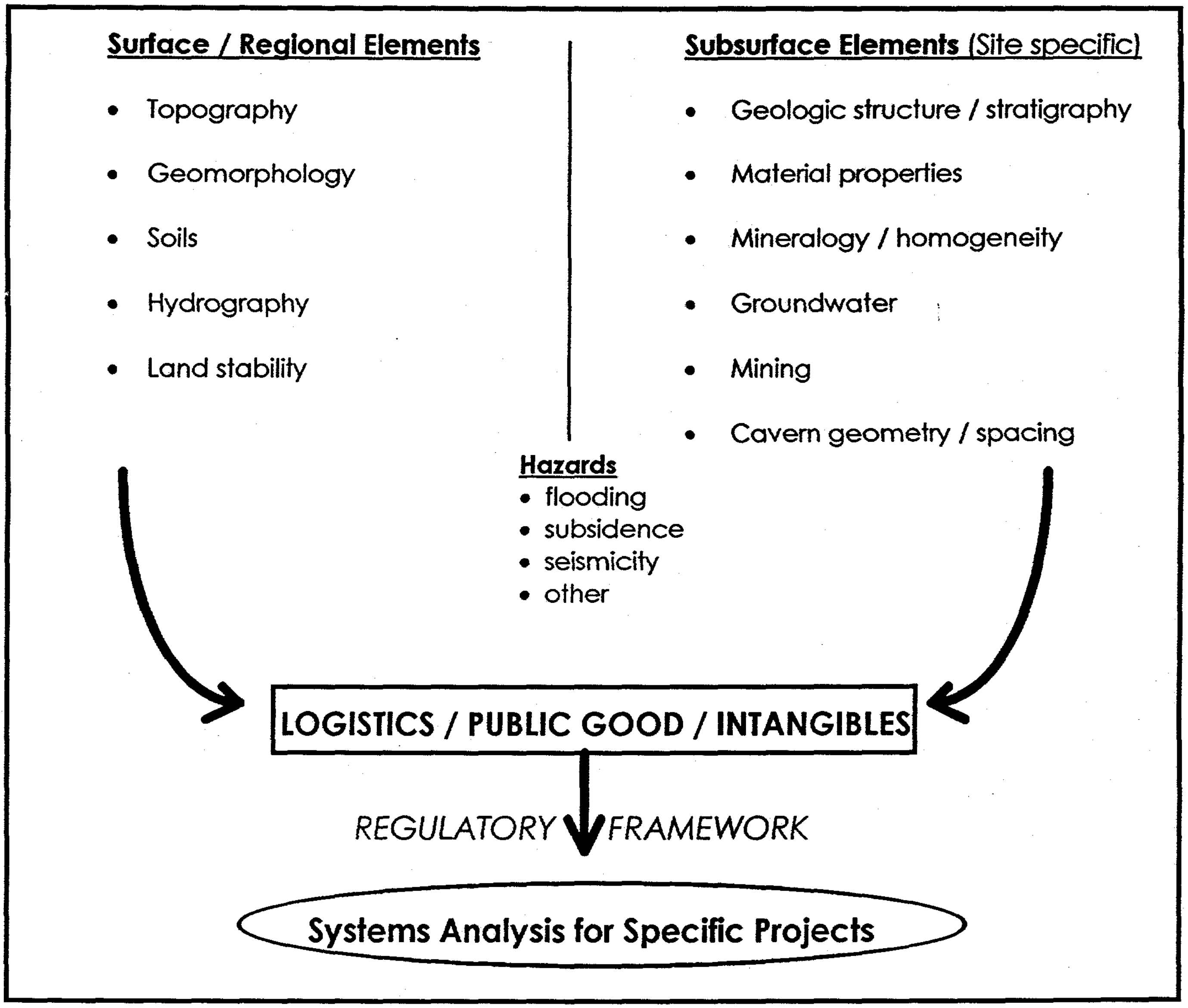


Table 1 Generalized Outline of Principle Elements of Geologic Site Characterization (GSC) for Storage and Mining Projects. The product of GSC is incorporated into regulatory applications and for *systems analysis*, which is not part of the geological report.

and where we store crude oil in our national SPR, or other products elsewhere.

The top of Boling Dome, TX, was recently mapped by 3D seismic reflection as part of the characterization necessary to develop toxic-waste storage caverns next to the Valero gas storage facility. The profiles revealed abrupt ledges which may be related to AZs. An off-dome 3D layout failed to find a turning wave from the steep flank. However, reprocessing of previous 2D data, stacking only from the outside, solved the problem.

Napoleonville Dome, LA, has been studied seismically as well, in an attempt to position additional caverns between complex brine galleries. The top of salt is relatively flat, apparently due to an active water drive in the river-levee point bars overlying the caprock, The overhang on the south side again could not be resolved with the same approach. A much more satisfactory resolution of a flank overhang was developed at Jennings Dome near Evangeline, LA, by piggy-backing closer-spaced data on a conventional 2D seismic regional group shoot. By stacking the data only from the outside, it was possible to define the overhang depth within 50 ft.

This improved quality of information allows engineering judgement to be less constrained by uncertainty, which in the past led to overconservatism. Thus, the caution that was previously factored into some storage decisions can now be lessened, and with equal or greater degrees of safety.

SOME HARD-LEARNED LESSONS (geologic) FROM STORAGE AND MINING PROJECTS

Choctaw Cavern 7 (uncontrolled leaching)

At Bayou Choctaw salt dome near Baton Rouge an 800 ft diameter lake formed in 1954 when the overburden over a brining cavern collapsed into the brine cavern below. With the advent of sonar surveying and controlled leaching, it is unlikely that such mistakes due to uncontrolled brining through the caprock would be repeated today (Neal et al., 1993). But even today, additional questions relative to the cause have arisen because of the peripheral location on the dome and likely faults in the caprock. The possibility of a similar collapse at nearby Cavern 4 has been evaluated but is presently thought to be unlikely.

Weeks Island (sinkholes / storage in mines)

A sinkhole at Weeks Island formed in 1990-91 over the edge of the mine as a result of geological, hydrological, and mine-induced factors. The location near the edge of the dome, astride a possible anomalous zone (AZ), set the stage for the mine configuration, following essentially natural boundaries created by geologic features. The AZ designation seems appropriate as black salt, blowouts, brine seeps, shearing, and a salt valley were identified even before the oil emplacement. Such anomalous features when occurring in multiples were subsequently conceptualized to comprise the salient elements of AZs, (Kupfer,1990; Neal, 1995) A second and smaller sinkhole was discovered in early 1995 over the edge of the mine, and in a trough between two areas of higher salt, possibly separating individual lobes or spines.

Mine geometry and excavation-induced stresses placed the mine periphery in tension, probably favoring crack development as early as 1970 (Ehgartner, 1993). Eventual incursion of undersaturated ground water traversed the 107 m (350 ft) salt back over the mine, allowing entry of brine into the SPR mine. Gradually increasing dissolution enlarged a void at the top of salt, creating the collapse environment for the sinkhole that formed circa 1990-91. Exploratory drilling and geophysics defined the void or crevasse beneath the sinkhole, enabling the introduction of saturated brine directly into the throat. The brine essentially arrested the continuing subsidence at the sinkhole, apparently as a result of controlling ongoing dissolution. Additional drilling diagnostics and hydrologic analyses determined that mitigation could be achieved by constructing a freeze wall around the sinkhole to effect groundwater control, prior to removing oil from the mine (Neal, 1995).

The lesson learned here is that storage of hydrocarbon products in room and pillar mines carries substantial risk, based on experience with sinkhole formation in at least six other Gulf Coast mines. The inability to perform maintenance grouting from within the oil storage facility was the primary detriment. The importance of geologic features, especially AZs, in localizing sinkhole occurrence is also stressed.

SPR gassy oil (AZs / gas in salt)

In early 1993 it was learned that a number of caverns within the SPR system had excessive amounts of gaseous hydrocarbons dissolved in the oil. The oil would require degassing prior to refining in many cases, and because the processing rate may be less than the drawdown rate criteria, cycling of oil and concomitant degassing is anticipated in order to maintain drawdown readiness [Oil and Gas Journal, 1993, 1994].

In a number of instances the gas content had increased, leading to the conclusion that the source originated from within the salt [Hinkebein, et al., 1994]. Gas in salt has long been a problem in conventional mining, leading to several fatal accidents following outbursts of gas and associated saltfalls [Molinda, 1988]. At Bayou Choctaw SPR Site, Caverns 18 and 20 showed higher than allowable gas content in March and May, 1993, and were identified as requiring treatment prior to drawdown. A possible correlation of gassy caverns and a shear zone trending N 75° E that transects the dome may exist; a similar N 45° W shear zone occurs at Bryan Mound [Thoms, 1993]. The apparent correlation with the *anomalous zone* (AZ) at Bayou Choctaw may be similar to that noted by Iannacchione et al. [1984] in his study of gas associated with salt outbursts in conventional mining. This correlation suggests that gas migrates through these AZs and into the adjacent salt at a faster rate than in normal salt. At Bayou Choctaw Caverns 18 and 20 are evidently in the salt adjacent to the AZ **(Figure 6)**.

The lesson here is that hydrocarbon storage requires thorough evaluation of salt properties, which includes intensive exploratory drilling and laboratory analysis. Special attention to location near AZs is required.

Napoleonville and Clovelly (Insufficient characterization; inadequate buffers)

Reports of cavern integrity and pressure maintenance problems at these domes are known for some caverns placed near salt stock edges, resulting in the inability to use certain caverns. At Clovelly it appears that caverns placed too close to (or in) the overhang are in salt that is inferior as a result of inadequate buffer **(Figure 7)**. The original design may have assumed a more conical salt stock, ignoring a large assymetry in the gravity anomaly and abundant well control. At Napoleonville shale layers were encountered in at least one brine cavern **(Figure 8)**, indicating that edge conditions had been encountered and that inadequate buffer existed. A similar encounter with shale was noted at one brine cavern at Bayou Choctaw.

The lesson here is that inadequate buffers can be costly, but that with more concerted characterization effort, most can be avoided. However, in some cases of legitimate uncertainty or insufficient data, trial and error may be necessary prior to cavern emplacement.

PERIODIC UPDATE REQUIREMENTS

The active life of solution mined storage caverns for liquid and/or gaseous hydrocarbon storage can extend for 40 years or more, as has been demonstrated at many domes. In fact, some brine caverns are now more than 50 years old. This time period is such that continual updating of the geological data base is essential. The conceptual understanding of salt dome processes and features is evolutionary and may

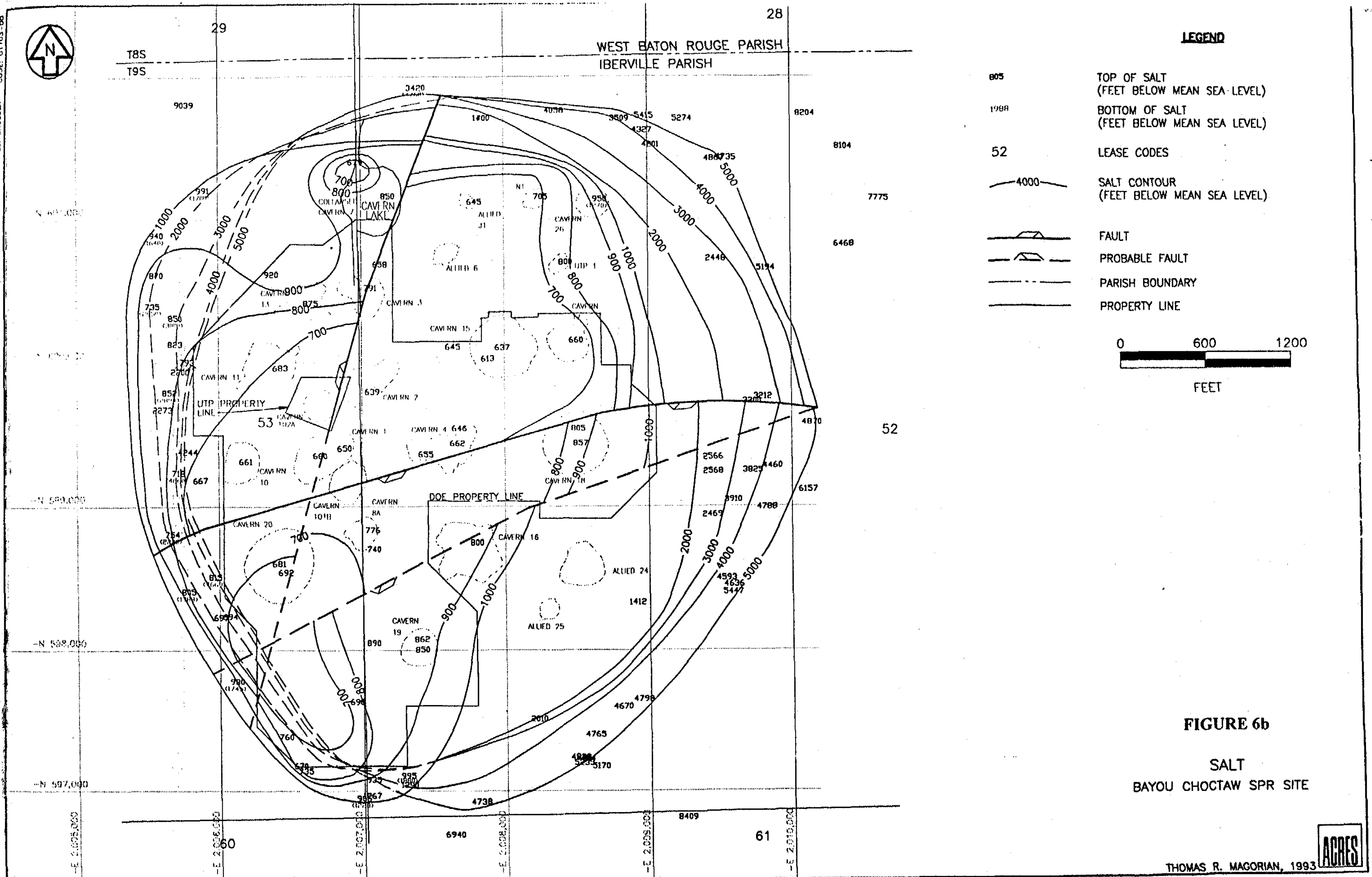


FIGURE 6b

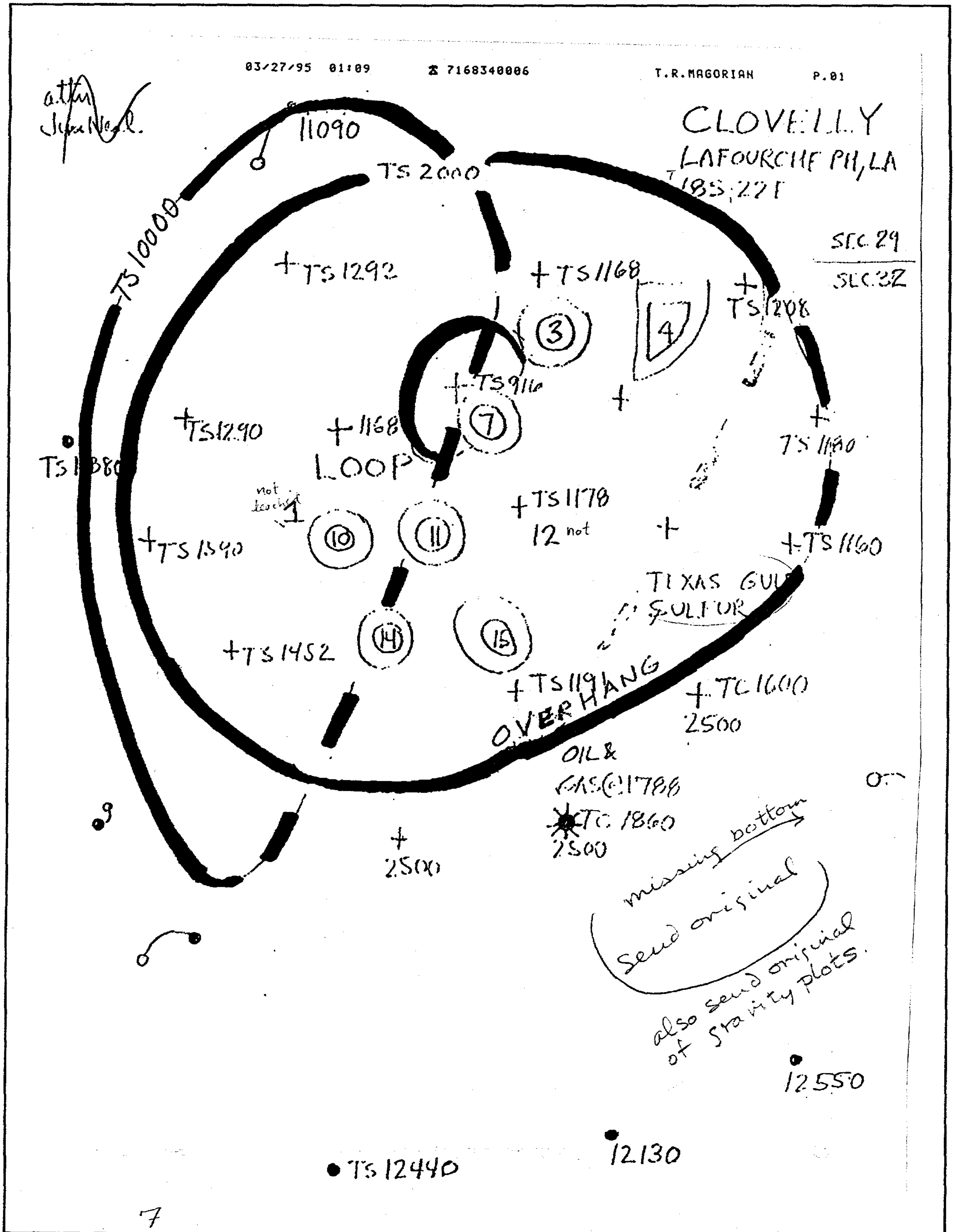
SALT
BAYOU CHOCTAW SPR SITE

THOMAS R. MAGORIAN, 1993

17-18

Fig. 6 Shear or anomalous zone (AZ) transects entire salt stock at Bayou Choctaw, LA, salt dome. SPR caverns 18 and 20 contain excessive gas, presumably related to the position astride the AZ.

draft



modify?

Figure ~~XX~~ 7. Salt Contours at -1000, 2000, and 10,000 feet, showing extreme overhang on east side of Clovelly Dome. Teardrop shape of salt stock has led to difficulties in cavern integrity as a result of insufficient space in overhang—which might have been ~~averted, as information was available at time of leaching to be~~ suspect of symmetric dome.

sufficient?

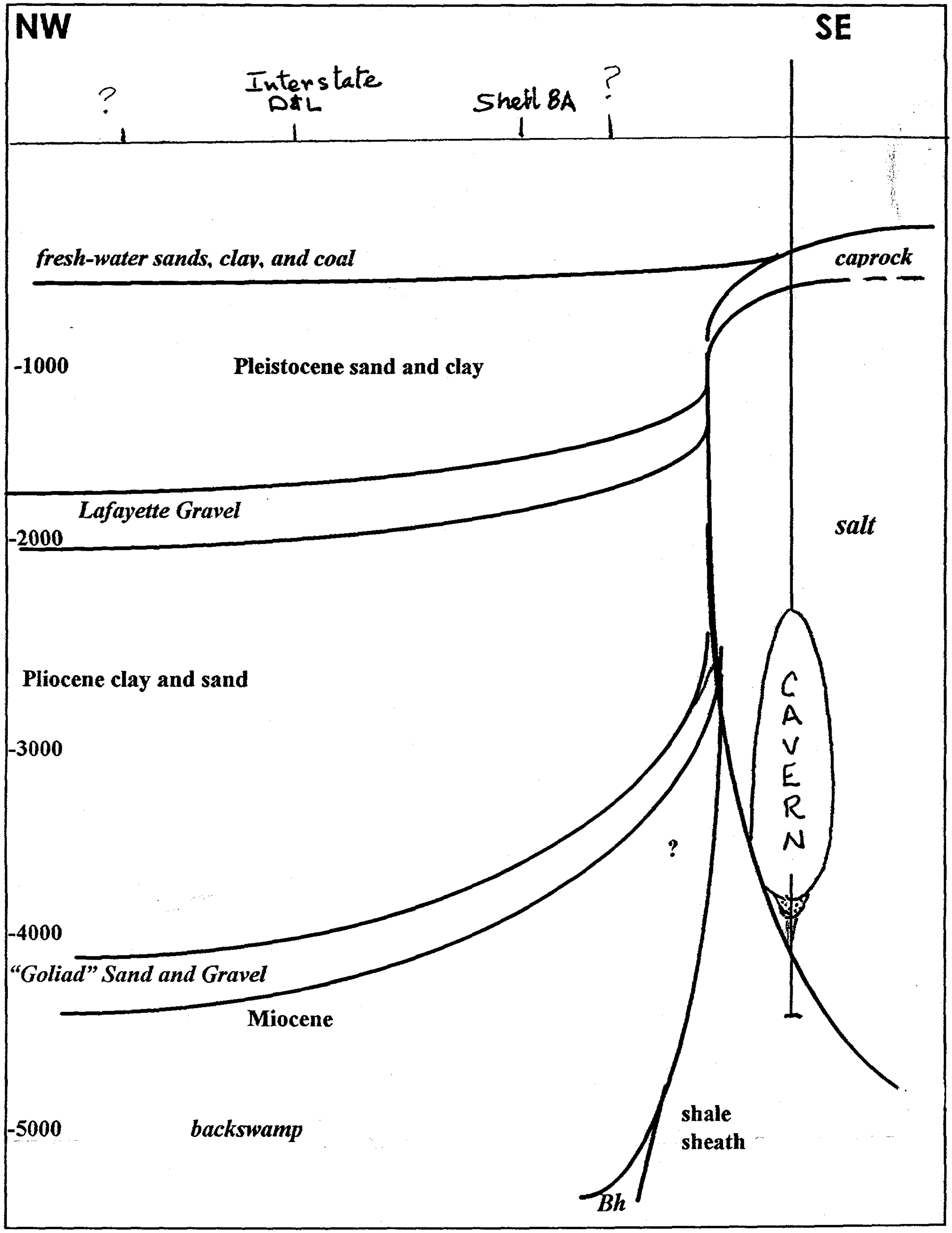


Figure ~~XX~~ 8 Conceptual diagram of westernmost cavern on Napoleonville dome, showing penetration of the salt stock into the overhang. Because of the fortuitous ~~presence of shale sheath~~, this cavern was not lost but easily ~~might have~~ been.

change the way in which we think about a particular problem or site. And some geologic processes are sufficiently active that significant changes can occur within the life of a storage project and can affect storage integrity.

We do not normally expect dramatic changes in our knowledge base, and yet it is necessary to realize geology is a young science that is changing and evolving at a rapid pace—sometimes faster than we can assimilate. Plate tectonic concepts, unspoken in many circles just 30 yrs ago, are still evolving, and new paradigms about salt flow tectonics that are perhaps equally revolutionary are occurring now and causing us to alter our traditional ways of thinking about things. All of this indirectly affects how we think about engineering applications, such as cavern storage projects.

Anomalous zones (AZs) are deviations from pure salt and may be common features to almost all domes, but they were not fully recognized and conceptualized until the last 20 years or so (Talbot and Jackson, 1987; Kupfer, 1989, 1990). They have been shown to affect cavern shape, and at some sites the storage operations–for several reasons. In many cases hindsight is required, where new information or understanding must be applied to existing facilities. Big Hill and Bryan Mound, TX, and Weeks Island, West Hackberry, and Bayou Choctaw, LA, are Strategic Petroleum Reserve sites which now reveal more complete geologic understanding than was available at the time the facilities were first instituted. (Magorian, Neal, various) The periodic updates conducted at these sites have provided added confidence for continued safe storage of crude oil.

Caverns undergo shape changes, because of salt creep closure, but especially when products are cycled and fresh or brackish water is introduced to displace products. Cavern enlargement thus occurs and sometimes overlying caprock is also involved. The continuing appraisal of safety margins based on salt thickness and dome shape are required and this may evolve along with dome understanding. The experience of SPR at Bayou Choctaw, LA, shows that periodic updating and monitoring of Caverns 4, 20, and 15/17 is essential to ensure cavern integrity and site safety because they were marginal at the outset.

Subsidence monitoring of all SPR sites has been accomplished at least annually and shown significant variation in amount from site to site. Part of the variation is caused by regional differences in the settling of the coastal plain sediments, but some is due to the nature of salt properties or other dome-specific features. West Hackberry is an example of extensive, major subsidence caused by multiple sources, in addition to the primary cause in cavern creep closure (Neal and Magorian, 1993). Some of the 10 inches of subsidence that occurred between 1987 and 1992 was caused by local and regional effects, but much of it results from salt creep closure of the SPR storage caverns below. This rapid rate is of concern where wellhead elevations are already near sea level. Continuing surveillance and reappraisal is clearly indicated. However, the understanding of the causes, rates, and magnitudes of the subsidence allows site operations to continue without apprehension.

Dome shape and associated structure does not change, but the availability and quality of logs from adjacent well fields has modified our *interpretation* at several domes. And with new interpretations or salt contours, our estimates salt edge-to-cavern safety buffers has changed—by 500 ft and more for some SPR caverns at Bryan Mound, TX (Neal and Magorian,1994).

Risk analysis of other geotechnical hazards must be continuously updated as new and refined information is made available. In this regard, earthquake, hurricane, and flooding potential are better understood from a threat and warning viewpoint than they were 15 years ago. This new information enables improved advance planning and emergency preparedness.

This update interval will depend on many factors, highly variable in every situation. Experience gained from the U. S. Strategic Petroleum Reserve may be applicable for other projects, some of which have made no attempt to systematically upgrade the initial geological site characterization reports, even when knowledge about some features or processes had evolved.

The simple fact is that operations change, people come and go, and things happen (to paraphrase one bumper sticker). And so is it any wonder that when we review reports that were written 15-20 years ago (and sometims even less) that we are aghast at some notions? Now geology usually doesn't change much in a few years, but our understanding of major concepts evolves and this is reflected in the details of our site reports. It is common knowledge that *credibility and authority are changingy*—sometimes slowly, and sometimes virtually overnight. This usually goes hand-in-glove with changes in conceptual knowledge.

How does one plan for all of this at the outset? We should acknowledge our soft spots up front. This may be easier said than done, but with honest self-appraisal we should at the least tentatively plan when updates are apt to be needed and how they could affect the system in question. But of course, without resource planning it simply won't happen.

CONCLUSIONS:

Caverns in salt are a very valuable resource, and in some locations a rare commodity because of limited salt availability. As such the GSC activities become a dollars and cents proposition. In all cases they require adequate characterization for health, safety, and environmental protection. If these requirements are not properly addressed, the result may lead to loss of facilities and even costly litigation.

Geologic site characterization is an ongoing process, not an event! *The task of site characterization must not stop after the initial effort and needs to be revisited every so often.* Regulatory requirements for GSC should include provisions for updating at least every 10 years.

We must recognize change:

- **Events** in the form of natural proceses never stop, and are usually unpredictable.
- **Man's actions** change many things , usually unwittingly.
- **Concepts evolve**, making much room for the next generation of geologists. They are sure to make much current geothinking obsolescent.
- **Authority evolves** with each new generation of people and knowledge.
- **Tools improve.** Data gathering and information processing surely will continue to improve.

Apply Specifics; Adjust Risk / Safety Evaluations All of this modified information base is required to revise the interpretation of safety and risk factors.

At outset of projects, recognize the following explicitly:

- **Quality, Uncertainty** (in data base)
- **Schedule Update Recurrence** (10 yr minimum)
- **Budget Planning** (essential)

Just a few examples of change demonstrated that GSC updates are important. Events happen--no doubt about it! Pay a little more up front, or maybe much more later!

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